Japanese-Style and Gravel-Box Incubation of Chum Salmon *(Oncorhynchus keta)* Compared at the Fry Stage

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JAPANESE-STYLE AND GRAVEL-BOX INCUBATION OF CHUM SALMON (*Oncorhynchus keta*) COMPARED AT THE FRY STAGE

by

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ABSTRACT

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Three successive broods of Big Qualicum River chum salmon (Oncorhynchus keta) were incubated and reared from fertilization to an early fry stage using two techniques: a Japanese-style hatchery technique (JSH), which uses ground water and keeper-channels, and a deep-substrate incubation technique (Box), which uses river water and a gravel medium. Both treatments were replicated each year. The combined effects of the higher temperatures and the lack of a deep gravel substrate resulted in time of development (to 50% emergence) being accelerated by 56 (±1) days in all JSH groups. At emergence, JSH fry were smaller and less advanced than the Box fry but survivals were the same. The JSH fry were ponded and fed Oregon moist pellets for the 8-wk time period created by the differences in techniques. This resulted in substantial size gain of these fry at the time of emergence of the Box fry. Their average fork lengths ranged from 54.5 to 60.4 mm (mean 57.5) vs. 35.8 to 36.9 mm (mean 36.4) in the Box fry; their mean wet weights ranged from 1503 to 2291 mg (mean 1955) vs. 400 to 433 mg (mean 412). Growth rates were calculated and all results are compared with other available sources.

Key words: chum alevins and fry, gravel incubation, Japanese keeper channel, deep-gravel incubator, growth, mortality, yolk-conversion efficiency

RÉSUMÉ

Bams, R. A. 1984. Japanese-style and gravel-box incubation of chum salmon (Oncorhynchus keta) compared at the fry stage. Can. Tech. Rep. Fish. Aquat. Sci. 1330: 23 p.

Au cours de trois années successives, des oeufs fertilisés de saumon kéta (Oncorhynchus keta) de la rivière Big Qualicum ont été incubés et élevés jusqu'au stade d'alevins naissants, selon une technique piscicole de style japonais (TPJ) (eau souterraine et canal d'alevinage) et une technique d'incubation en bac à substrat profond (eau fluviale et gravier). Les deux traitements ont été répétés chaque année. L'effet combiné de températures élevées et de l'absence d'un substrat gravelleux profond a fait avancer de 56 jours (± 1) le temps de développement (jusqu'à une émergence de 50% des alevins) chez tous les groupes TPJ. À l'émergence, ces alevins étaient plus petits et moins développés que ceux produits en bacs, mais la survie était la même. Après le lâcher étangs, les alevins du groupe TPJ ont été nourris de boulette humides Oregon pendant les huit semaines de différence entre les techniques. Au moment de l'émergence des alevins incubés en bacs, les autres s'étaient beaucoup développés: leur taille moyenne à la fourche variaient de 54,5 à 60,4 mm (moyenne de 57,5), comparativement à entre 35,8 et 36,9 mm (moyenne de 36,4) pour les alevins incubés en bacs, et leur poids humide moyen allait de 1,503 à 2,291 mg (moyenne de 1,955), au lieu de 400 à 433 mg (moyenne de 412). On a calculé les taux de croissance et comparé tous les résultats avec les autres sources disponibles.

Mots-clés: alevins vésiculés et alevins nageants de saumon kéta, incubation sur gravier, canal d'alevinage de style japonais, incubateur à substrat profond, croissance, mortalité, efficacité de conversion du vitellus

INTRODUCTION

Canada's federal-provincial (British Columbia) Salmon Enhancement Program (SEP) was launched in 1977. It aimed at doubling the annual catch of Pacific salmonids by 1990. One of the strategies to reach this goal was artificial propagation of all major species (SEP Annual Report for 1977). At that time, recent reports on the performance of Japanese chum hatcheries indicated good returns on investment and seemed to warrant a trial of this technology to gain experience and evaluate its performance under Canadian conditions. Two independent pilot operations were initiated in 1976: one on Thornton Creek (Ucluelet Inlet, west coast of Vancouver Island) and one on Rosewall Creek (100 km north of Nanaimo, on the east coast of Vancouver Island). The former operation was carried out by members of the Salmon Enhancement Program (Bailey 1979), the latter by staff of the Pacific Biological Station, Nanaimo (this report). The project was designed and initiated by C. Groot; completed, analyzed and written up by R. A. Bams. This report documents the performance of the technique to the time of juvenile release. Adult return data will be reported elsewhere.

MATERIALS AND METHODS

Central to the Japanese-style of rearing chum salmon is availability of a groundwater supply with a temperature exceeding that of the parent stream. Incubation at elevated temperatures accelerates egg and alevin development and the fry reach the swim-up stage preferably from 6 to 8 wk earlier than their natural counterparts that are developing in the river gravels. The time thus gained is used for intensive feeding, which produces fry weighing from 1 to 2 g at the time the river fry emerge at perhaps 0.4 g. Standard protocol is to release the reared fry simultaneous with the natural fry run.

Water Supply. The Rosewall Creek facility (Smith 1969) has two independent water supplies, river water and ground water. Both supplies are of very high quality. The river water is pumped from a sub-gravel gallery, installed 60 cm below the natural river bed, and was filtered to 5 μm for this experiment. Chemical and temperature characteristics closely reflect those of the river. Ground water is pumped from several wells, drilled some 30 m into the alluvial fan underlying the area. This aquifer is believed to be fed primarily from the Rosewall Creek watershed, which extends some 8 km above the hatchery site and covers about 18 km^2 of mostly wooded lowland and hillsides rising to about 1000 m. The water as pumped contains little NH_3, CO_2, or H_2S and appears to have had a retention time of only from 4 to 6 months. The groundwater supply is aspirated before storage. Both sources are gravity fed from 10 m high reservoirs of 22 m^3 capacity, and have dissolved oxygen levels close to saturation at all times. Some characteristics of the temperature regimes of both water sources are shown on Figure 1 and Table 2.

Channels. Japanese procedures and techniques, as described by McNeil 1977; Moberly and Lium 1977; and other sources, differ in details, but a generalized methodology can be deduced. Accordingly, two pilot-scale "keeper-channels" were constructed outdoors, each channel measuring 30 m long by 180 cm wide and 30 cm deep. They were made of concrete, had covers of 5x30 cm cedar planks, covered, in turn, by two layers of black polyethylene sheeting. The concrete bottom of both channels was covered with a loosely continuous, single layer of fairly sharp gravel, measuring from 19 to 38 mm in diameter. The brood was introduced to the channels at the late eyed-egg stage shortly before hatching, and evenly distributed on taut plastic screens (Lumite) suspended 8 cm above the floor and covering the length of the channel. The screens had gaps between one-another and alevins dropped off the edges to the gravel beneath upon hatching. Egg density was approximately 12,000 per m^2. Water flow was maintained at 80 L/m and was periodically checked at the outlet. At a depth of 15 cm this flow gave an average linear velocity of about 33 cm/hr. Flows were set with underground PVC ball valves, one for each channel, and were evenly distributed by means of a manifold extending the width of each channel. Fry emergence was voluntary once stainless steel screens (10 holes per 3 cm) were removed from the down-stream ends. Flows were increased at times to increase rate of egress.

Boxes. Two deep-gravel incubators (Bams and Crabtree 1974), each measuring 1.2x2.4x1.2 m deep, were equipped with PVC-plastic liners, an upwelling water supply, a pea- and birdseye-gravel layer situated 20 cm off the bottom and impervious to descending alevins, and an incubation area 90 cm deep, consisting of 19 to 38 mm dia. gravel. Eggs were introduced at the late eyed stage, in 8 layers, and were supplied with 100 L/min river-water per box. Fry emergence was voluntary. All fish emerging from each overflow were trapped in a 60x60x90 cm deep marquisette pen suspended in a large fiberglass tank.

Brood. Eggs were obtained in all years from the Big Qualicum River chum stock, on one (1978) or two successive days. Fertilized and water-hardened eggs were taken to the Rosewall facility, pooled in groups of about 200 L each, disinfected for 10 min in 50 to 100 mg/L Wescodyne, and distributed alternatingly to two separate banks of incubators differing only in water supply. One treatment was assigned to each bank and the two groups were held separate throughout the incubation and rearing phases. The "control" population was kept on creek water throughout; the experimental group was usually on groundwater to accelerate development as much as possible. The eyeing incubators were 30 cm in dia. by 20 cm deep, had upwelling water supplies, and held approximately 25,000 eggs each. Fungus was controlled with routine 200 mg/L malachite green treatments 1 h in duration. All egg counts were volumetric, calibrated to within 1% with an electronic egg-counter, and had an accuracy of about ±5%. All fry were hand counted. Samples were taken non-selectively from daily accumulations of fry, preserved in 10% formalin and processed not less than 8 wk later in the laboratory for individual fork length (to nearest 0.2 mm) and total wet weight (in mg). Stage of development was assessed by K_D-index (Bams 1970) calculated as

$$K_D = \frac{10 \cdot \sqrt[3]{\text{weight (mg)}}}{\text{Length (mm)}}$$

Rearing. Channel fry migrated voluntarily from the two keeper-channels to two outside concrete rearing ponds. Each raceway measured 15.2x2.4 m and held water to a depth of 60 cm. Flow rates were gradually increased from 225 to 450 L/m over the rearing period, which gave an exchange rate from 60 to 120 %/h, or one exchange every 96 to 48 m. Fish were machine-fed Oregon moist pellets (OMP) at 15-m intervals during daylight hours, at manufacturer's recommended chart rates and sizes. Rates were adjusted weekly on the basis of fish size and biomass present. Fencing and netting surrounded both ponds to limit predation by small mammals and birds.

RESULTS AND DISCUSSION

A. INCUBATION PHASE

Survival. Numbers of green eggs, eyed eggs, and fry, and survivals are given for all units of both treatments in all brood years (Table 1). Green-egg to eyed-egg survival was marginally lower in river water than in groundwater in all years, grand mean survivals were 81.3 and 84.8% respectively. The difference is not significant statistically (paired t-test: $t=1.292$, $df=2$, $P>0.2$). Green-egg to fry survival varied from 72.9 to 82.6% in the river water (gravel boxes) and from 72.1 to 86.9% in the groundwater (keeper channels). Unweighted treatment averages for the three years were 77.9 and 80.6% respectively; this difference also is not significant statistically (2-sample t-test: $t=0.883$, $df=10$, $P>0.2$). These survivals are comparable to those routinely obtained in Japan and as described by Bailey 1979, and are considered satisfactory.

Temperature and Rate of Development. Temperature regimes within treatments were similar among years. To demonstrate the difference between the treatments within years, Figure 1 shows a composite of the accumulating temperature units (t.u., in C°), time of occurrence of three incubational events, and mean lengths and developmental indices (K_D) of the fish in time (in days from fertilization) for the 1976 brood. Although the figure is complex, it actually facilitates detailed comparisons. For example, the heat differential can be seen to build gradually to a maximum of 389 t.u. at about day 150. However, the largest time differential at the same number of t.u. occurred at about 600 t.u., reached in 80 days versus 139 days respectively, an increase in rate of t.u. accumulation of 74%. Since rate of development does not accelerate linearly with temperature in the ranges used here (Alderdice and Velsen 1978) the rate of development showed a somewhat lesser increase over the same time. We can read from the graph that a mean fork length of 27.4 mm was reached on days 88 and 139, respectively, which represents a rate increase of only 58%. This reduction

in acceleration at the higher temperature regime is reflected in other events occurring relatively later (i.e. at a higher t.u.) at the higher temperature. This is best illustrated by the calculated t.u. to 50% emergence at a constant stage of development (penultimate line of Table 2). T.u.-values to various life stages and events agree well with reported values for nine other B.C. chum stocks incubated in gravel-incubators and keeper-channels (Banford and Bailey 1979).

B. EMERGENT FRY PHASE

Rates of emergence. In the first year (BY 1976) fry emerged much faster (expressed as %/day) from the gravel boxes than from the keeper channels, the middle 70% of the runs took 9 and 13 days, respectively (Fig. 2, upper half). In the second and third year the same segment of the runs took a more even 5.5 and 7.5, and 6.0 and 7.5 days, respectively (Figs. 3,4, upper halves. It is not known why both fry runs were about 50% slower in the first year than they were in the later two years.

Size and stage of development at emergence. In the first year, fry emerged from both treatments at a relatively early stage of development, i.e. generally prior to reaching maximal larval wet weight. This resulted in mean fry lengths increasing linearly during most of the emergence period (Fig. 2). Clearly, box fry emerged at consistently and considerably larger average sizes than the channel fry at any one time during the runs, but the overall ranges observed overlapped. During the mid-part of the runs the K_D-values averaged 2.058 for the box fry and a much more immature 2.095 for the channel fry. Using the decline rate in K_D-index established for alevins in the channels for day 180 (Fig. 1, at 0.0046 units/day) and assuming that normal natural emergence of these fish would have occurred at K_D=2.00, it follows that the box fry emerged prematurely by about 12 days (Bams 1970). Using the same conversion factor, the channel fry emerged an additional 8 days prematurely, for a total of 20 days, based on their mid-run K_D-value.

In the second year the difference between the two treatments in stage of development at emergence increased: the box fry were less premature and the channel fry more so, as indicated by the estimated K_D-values at mid run, which were 2.045 and 2.116 respectively. Using the decline rate established for the 1976 brood, these values correspond to 10 and 25 days early emergence. Emergence timing and fry sizes are shown on Figure 3. In the third year the estimated K_D for the box fry at mid-run declined even further, to 2.011, while that of the channel fry, at 2.086, was similar to that of the first year. These values correspond to about 3 and 19 days of premature emergence, respectively. Average values of premature emergence for all years were 8.3 days for the box fry, and 21.5 days for the channel fry.

The varying degree of immaturity of the fry at emergence is clearly reflected in their recorded average lengths (Figs. 2-4). Normal fry emergence occurs near the developmental stage of maximum larval wet weight (Bams 1970, 1983; Heming 1982). This stage was reached only by the

box fry, at from 70 to 80% completion of emergence, in the last 2 experimental years. All channel fry, and the box fry in the first year, failed to reach this developmental stage during their period of emergence. Premature emergence is not always observed with box fry, cf. review by Bailey (1979). As discussed by Bams (1983), premature emergence is likely to be a disadvantage when fish are released directly into natural surroundings, but it may be an asset under certain hatchery conditions.

C. FEEDING PHASE

The accelerated development rate obtained with incubation in ground water and the more premature emergence from the keeper channels culminated in the median time of emergence advancing by 55, 57, and 56 days in the three years (Table 2). All channel fry were marked with a double fin clip upon emergence and reared in two outdoor ponds for the time available to emergence of the box fry, Table 3. Rearing was terminated as fish were released from the ponds, roughly in synchrony with marking and release of the unfed, spontaneously emerging gravel-incubator fry.

Growth achieved over this period was substantial, Table 4. The grand average (2 ponds, 3 years) daily growth rate was 0.916% per day calculated on ln. lengths, and 3.05% for ln. weights, at an averaged temperature of 7.0°C (range of weekly means was 6.2 to 8.3°C, Table 4). This growth rate is identical to that shown by Shelbourn (1980) at 3.0% per day at 7.0°C (by interpolation of his data obtained at 4.8, 10.0, and 14.9°C, Fig. 5) on chum fry held in small tanks in fresh water and fed OMP to excess. Bailey (1979) reported average growth rates of 2.57 and 2.74% per day at 6.4°C for Thornton Creek keeper-channel chum fry, reared on OMP at a density of about 475 thousand fry in each of two 10.5x5.5 m outside ponds. These two values also agree very closely with Shelbourn's interpolated rate (about 2.7% at 6.4°C) and, hence, with the rates observed in our tests. Growth rates reported by Bams (1983) obtained on chum fry incubated in experimental keeper-channels and reared on OMP in small indoor tanks were consistently somewhat less than all others reported here.

Variability in growth rate among years in this test series (means were 3.49, 2.92, and 2.74%, respectively) is adequately explained by differences in mean rearing temperatures associated with the heat budgets of the two water sources available. It appears, therefore, that Shelbourn's original data fit a variety (temporal and geographical) of Vancouver Island chum stocks very well and comprise a useful standard of growth for freshwater rearing of chum using OMP. Shelbourn's data points and the graph used for interpolation are reproduced as Figure 5.

The final outcome of the incubation trials, using two different incubation techniques and temperature regimes, and feeding the accelerated group for the time available, is shown on Table 5. Very large and consistent differences in size between treatments were demonstrated, while differences in survival were relatively minor and inconsistent.

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Table 1. Numbers and survivals to eyed egg and fry migrant stages of chum salmon incubated in deep-gravel incubators and Japanese keeper-channels, for three brood-years, plus totals and weighted means.

		Total egg no.(K)[c]			Eggs planted			S%, from	
BY[a]	Source[b]	Green	Eyed	S%[d]	Units[e]	No(K)	Fry(K)	Eyed	Green
1976	Bx	483.0	417.0	86.3	N	190.8	179.3	94.0	81.1
					S	226.2	216.5	95.7	82.6
	Ch	521.2	456.4	87.6	N	232.5	225.0	99.2	86.9
					S	223.9	211.6	94.5	82.7
1977	Bx	652.1	535.4	82.1	N	535.4	258.3	96.0	78.8
					S	(incl.)[f]	255.7	(incl.)	(incl.)
	Ch	652.1	592.5	90.9	N	280.5	262.0	93.4	84.9
					S	280.9	257.6	91.7	83.3
1978	Bx	590.1	445.9	75.6	N	223.0	215.1	96.5	72.9
					S	223.0	215.3	96.6	73.0
	Ch	661.8	495.6	75.9	N	200.0	189.9	95.0	72.1
					S	250.0	241.7	96.7	73.4
Totals and Means	Bx	1725	1398	81.1	-	1398	1340	95.8	77.7
	Ch	1835	1544	84.2	-	1468	1388	94.6	79.6

[a]BY = brood-year(s).

[b]Bx = box = deep-gravel incubator; Ch = channel = keeper-channel.

[c]No = number, K = thousands.

[d]S = survival over stages indicated, in percent.

[e]N = north unit, S = south unit.

[f]incl.= the value for this unit is included in the one given immediately above.

Table 2. Estimated day (from fertilization) and accumulated temperature units (t.u. in C°) at three stages of development of chum salmon alevins, obtained with 2 incubational treatments during 3 years. Final gain in days is given for time of 50% emergence. Also given are the temperature ranges observed over the successive time periods.

Stage and Temperature	Broodyear 1976		1977		1978	
	Box[a]	Channel[b]	Box	Channel	Box	Channel
Fertilization	0/0[c]	0/0	0/0	0/0	0/0	0/0
temp. range	1.9-7.8	7.7-7.2	0.2-7.6	7.8-9.2	0.5-7.5	9.1-7.5
50% hatching	(114/481)[c]	71/533	(106/445)	58/511	(105/472)	61/514
temp. range	3.6-8.4	7.2-6.8	5.4-9.0	9.2-7.8	4.2-7.8	7.6-6.5
5% emergence	175/845	119/846	169/927	109/870	165/878	105/825
temp. range	7.7-8.9	6.8-6.8	9.0-7.8	7.8-7.7	6.7-6.8	6.6-7.5
50% emergence	180/888	125/887	173/960	116/924	170/916	114/892
Adjusted t.u.[d]	994	1063	1048	1144	942	1059
Actual gain[e] (days)	-	55	-	57	-	56

[a]Box = gravel incubators = river water.

[b]Channel = keeper channels = ground water.

[c]First figure = days following fertilization (±1 day); second figure = t.u. in C°; brackets indicate reduced precision (not less than ±2 days).

[d]t.u. value to 50% emergence adjusted for premature emergence, i.e. calculated value that would have been observed at normal natural emergence, see text.

[e]Gain = difference in median times of fry emergence between gravel incubators and keeper channels.

Table 3. Numbers of marked fish (in 1000's) and dates of keeper-channel chum fry, when introduced to two rearing ponds and when released upon completion of rearing period.

BY[a]	Pond	Source: North channel	Source: South channel	Source: Total	Combined date, median (range)	Release[b]: by pond	Release[b]: Total	Combined date, median (range)
1976	1	132.7	82.5	215.2	Mar 30	212.1		May 25
	2	90.4	126.9	217.3	(Mar 21/Apr 8)	214.7	426.8	(May 20/30)
1977	1	155.7	98.7	254.5	Mar 18	250.2		May 15
	2	96.0	155.2	251.2	(Mar 10/29)	248.0	498.1	(May 15/18)
1978	1	96.0	79.6	175.6	Mar 24	151.5		Mar 20
	2	90.9	160.6	251.5	(Mar 16/29)	244.5	396.0	(May 15/26)

[a]BY = brood year.

[b]Maximum estimates based on known mortalities only, since marking.

Table 4. Growth performance of keeper-channel chum fry of three brood-years in concrete ponds at Rosewall Creek hatchery. Weekly values are means for two samples, one from each of two ponds, usually comprising 50 fish each.

	Broodyear 1976			1977			1978		
Week	Length [a]	Weight [b]	t [c]	Length	Weight	t	Length	Weight	t
1 [d]	37.5	450	6.5	39.1	559	7.7	38.3	484	6.9
2	39.4	523	6.6	40.8	666	6.2	40.1	553	6.8
3	41.8	671	6.9	43.1	772	6.4	42.0	686	6.5
4	45.3	862	6.9	45.1	911	6.2	45.1	854	6.4
5	49.1	1118	7.0	49.2	1206	7.0	48.3	1050	6.7
6	52.6	1390	7.6	52.6	1535	7.4	50.5	1197	6.6
7	56.4	1760	8.3	54.9	1764	7.9	54.5	1503	8.1
8	60.4	2291	7.4	57.7	2071	7.5	-	-	-
$G(\%.d^{-1})$ [e]									
Pond 1	1.014	3.42	7.15	0.882	2.97	7.04	0.883	2.80	6.86
Pond 2	1.056	3.55	7.15	0.855	2.86	7.04	0.803	2.68	6.86
$Ln(L) = a + b(lnW)$ [f]									
pond	(1)	(2)		(1)	(2)		(1)	(2)	
a	3.862	3.858		3.836	3.838		3.865	3.865	
b	0.296	0.298		0.299	0.299		0.314	0.300	
r^2	0.998	0.998		0.999	0.998		0.997	0.995	

[a] Length = fork length in mm.

[b] Weight = total wet weight in mg, on preserved samples of fish.

[c] Mean daily average pond temperatures, in C°.

[d] Week 1 samples were taken respectively 7, 12, and 10 days following median loading date (Table 3) of the ponds in the 3 years.

[e] G = daily growth (length and weight) rates, calculated on ln x, usually of final 6 sample dates only; temperature is mean value for entire rearing period.

[f] Relationship between sample mean lengths and weights, for each pond, by broodyear.

Table 5. Average statistics[a] and their differences (Δ) for both treatments at median times of release, for all broodyears.

Broodyear	1976			1977			1978			3-year average		
Statistic	Box	Channel	Δ%	Box	Channel	Δ%	Box	Channel	Δ%	Box	Channel	Δ%
Survival(%)	94.9	94.4	-0.5	96.0	86.4	-9.6	96.5	80.8	-15.7	95.8	87.2	-8.6
Length (mm)	35.8	60.4	+69	36.9	57.7	+56	36.6	54.5	+49	36.4	57.5	+58
Weight (mg)	400	2291	+473	433	2071	+378	402	1503	+274	412	1955	+375

[a]Survival is from eyed egg to released fry and is corrected for extraneous losses. Lengths and weights of box fry are means for the 4 sample dates surrounding median times of emergence (n=8), those for the channel fry are from the final sampling day (n=2).

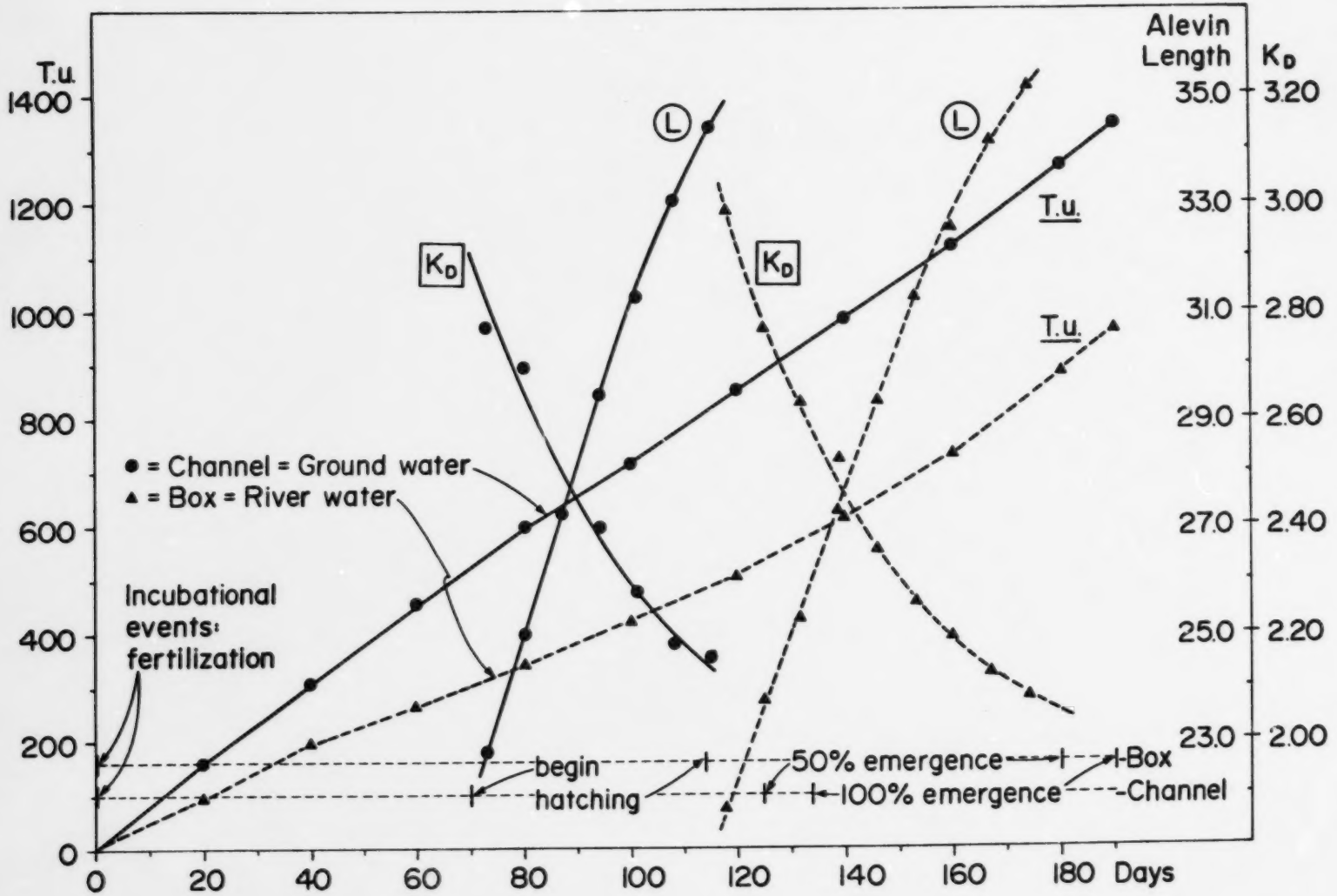

Fig. 1. Heat budgets (t.u., in C°) and larval fork lengths (L, mm) and K_D-values in time, from fertilization to emergence, in two incubational treatments at Rosewall Creek hatchery, on chum salmon of the 1976 brood year.

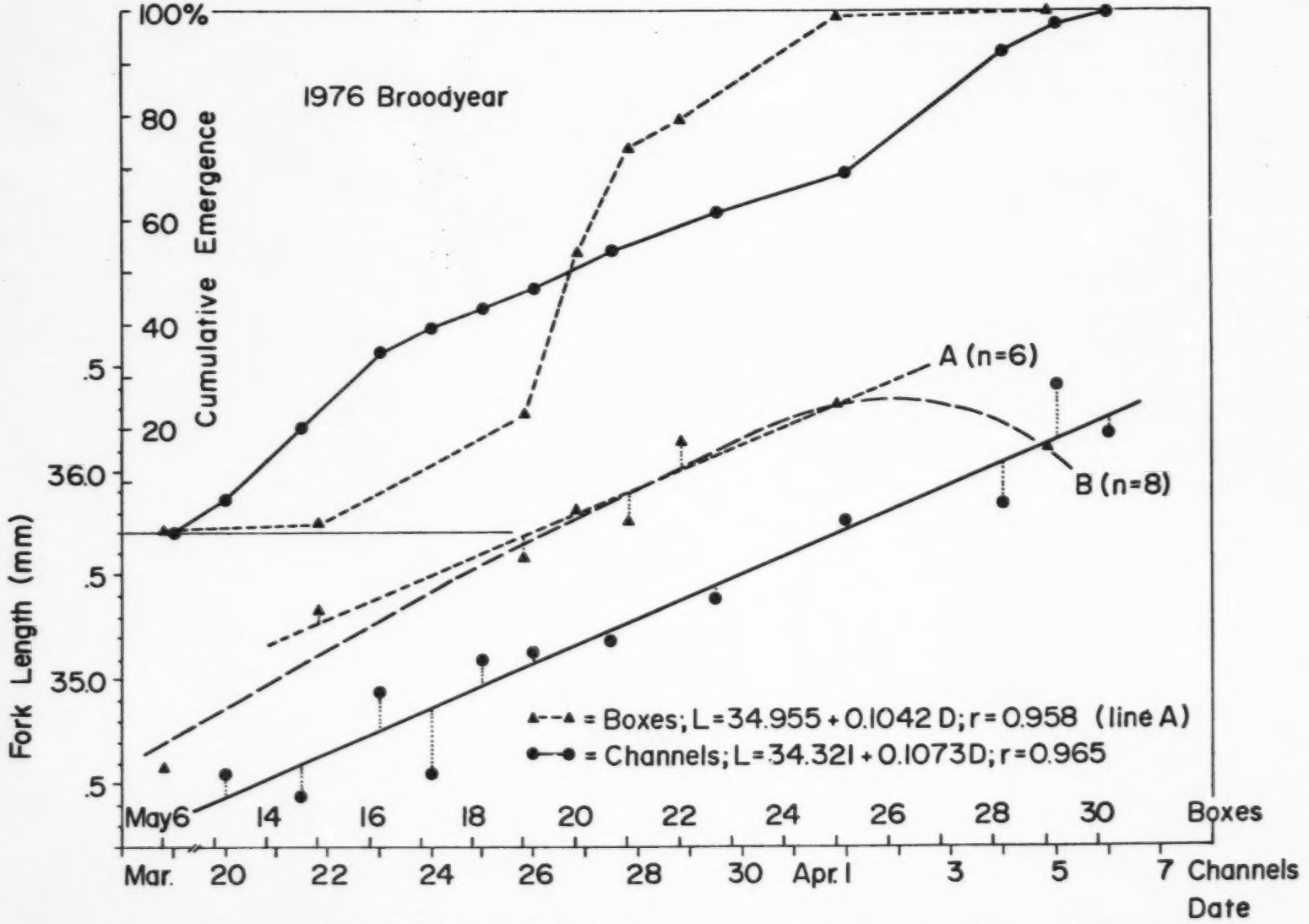

Fig. 2. Cumulative emergence (upper) and fork lengths (lower) in time, of chum fry incubated by two incubational techniques, for brood year 1976. Line A represents linear regression through 6 central points, line B is by eye, utilized all 8 points, and conforms with lines obtained for 1977 and 1978 broods.

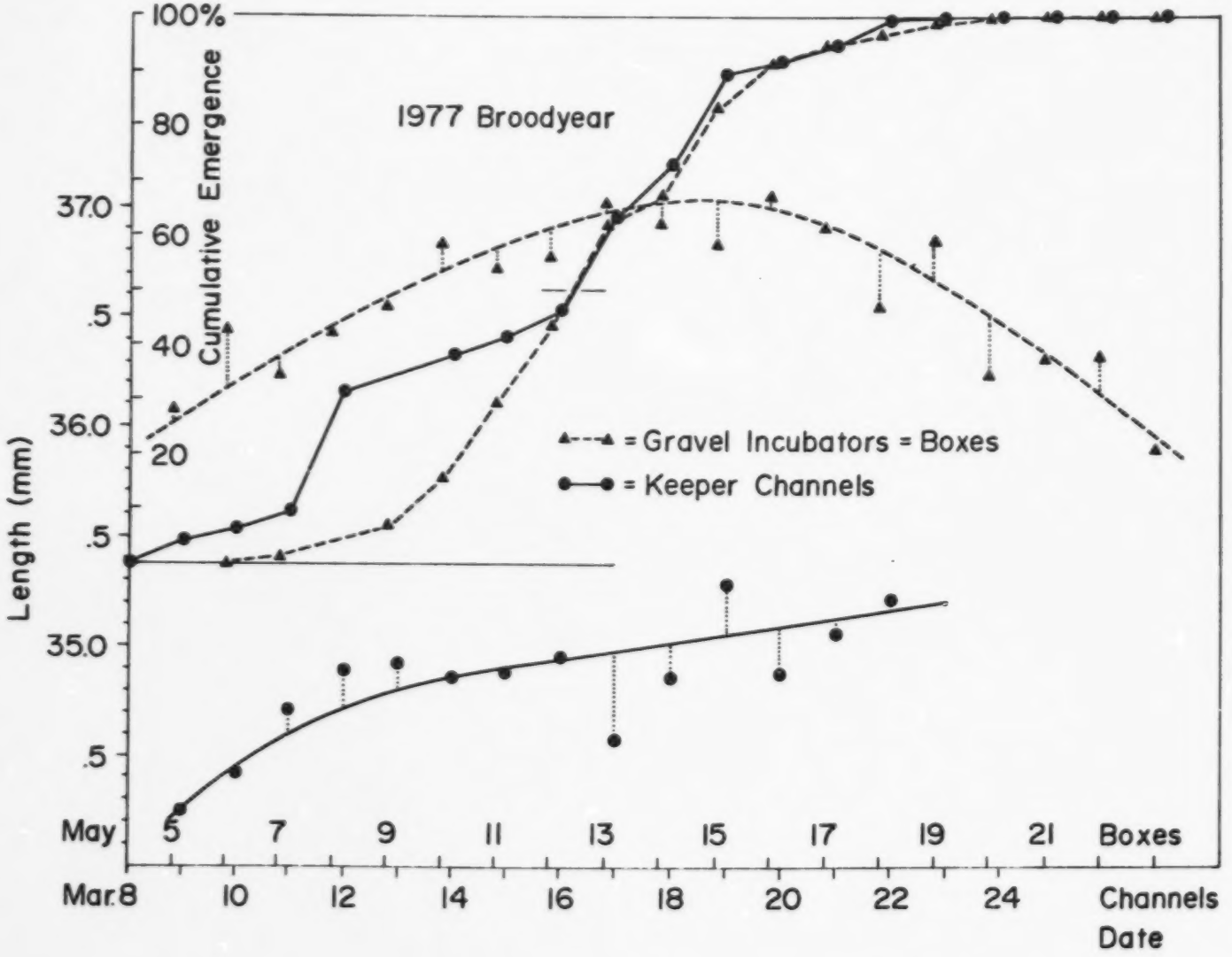

Fig. 3. Cumulative emergence and fork lengths in time, of chum fry incubated by two incubational techniques, for brood year 1977.

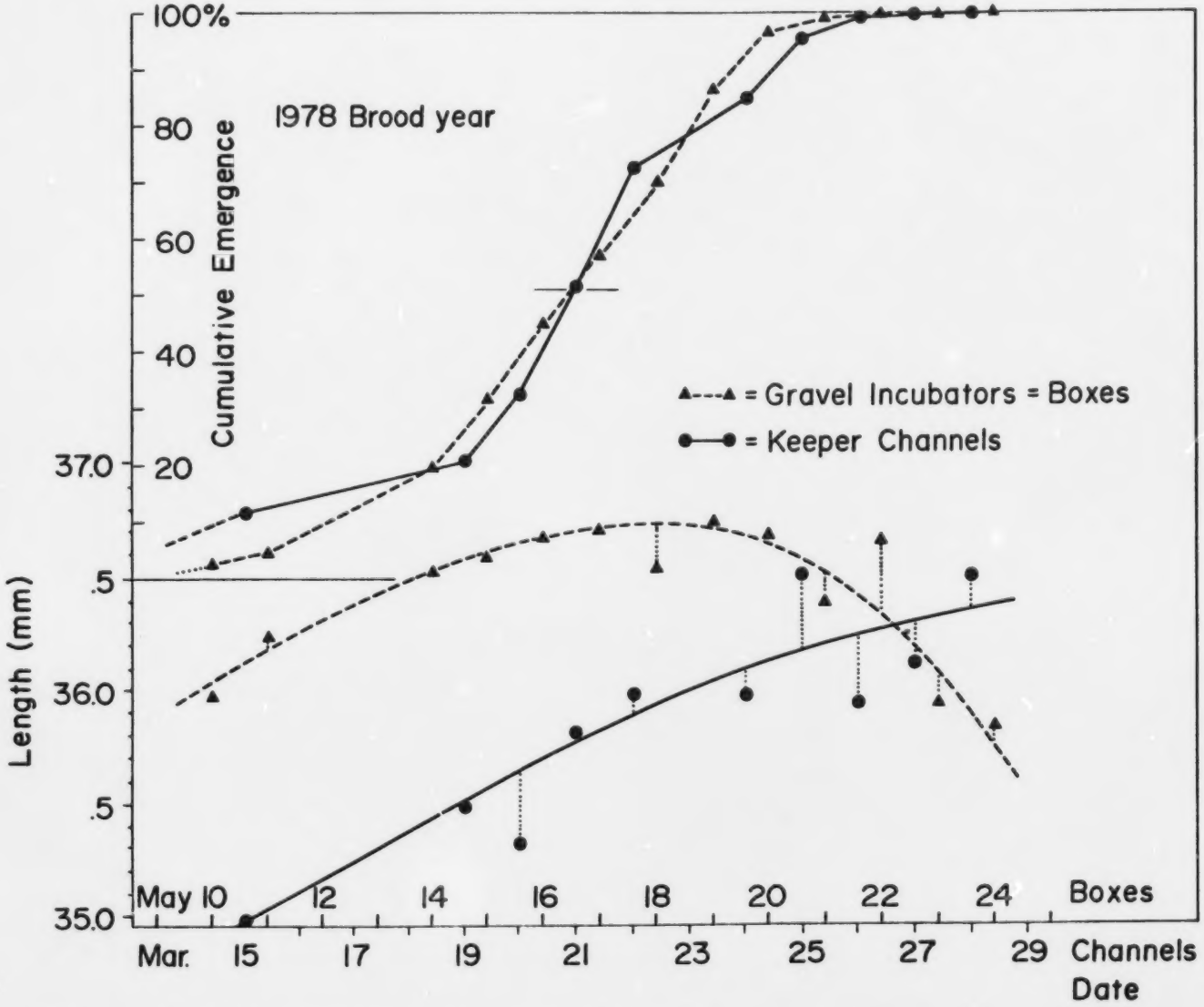

Fig. 4. Cumulative emergence and fork lengths in time, of chum fry incubated by two incubational techniques, for brood year 1978.

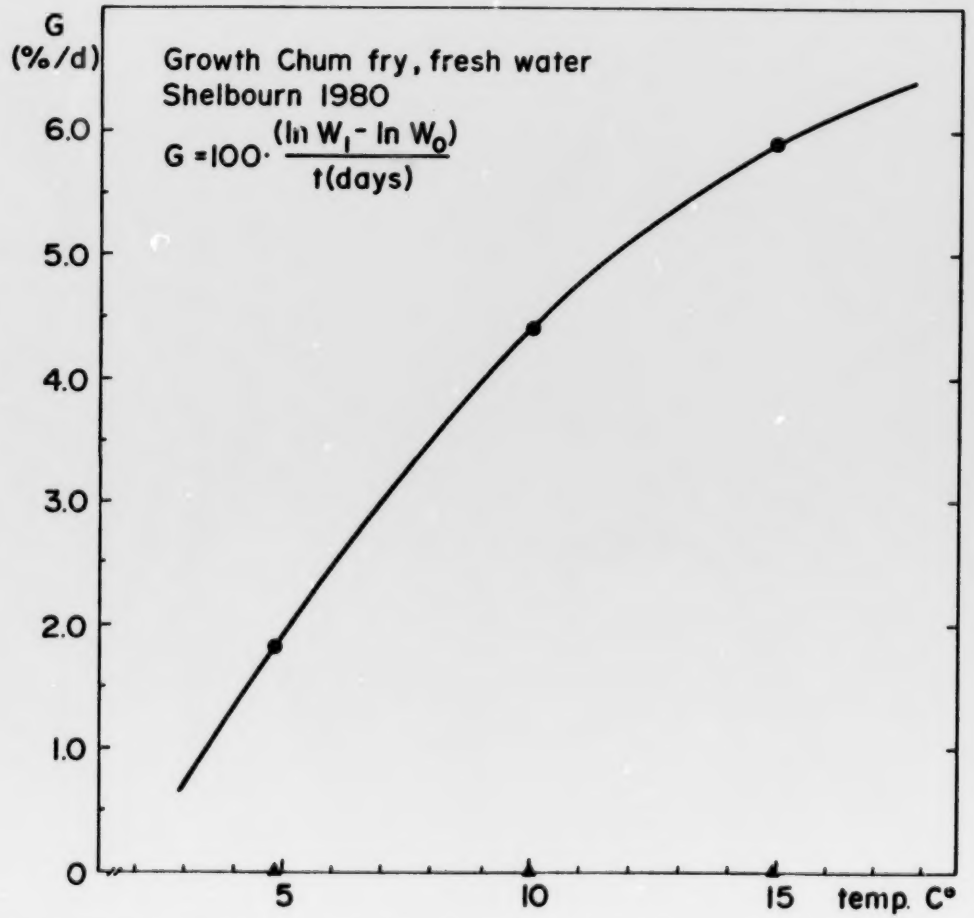

Fig. 5. Daily growth rates of chum fry at constant rearing temperatures. Data points from Shelbourn 1980.